Experimental Determination of the Effects of Transient Operations of Fuel Cell Stack on Heat Transfer and Temperature Distribution in the Electrodes

Final Report

Dr. Kalil A. Alkasab

Period Covered: 3/9/81 to 1/19/90

Cleveland State University
Euclid at E. 24th Street
Cleveland, Ohio 44115

Grant Number NCC 3-17

CSU Cleveland State University

Fenn College of Engineering

Mechanical Engineering Department
Main Classroom Building, Room 219
Euclid Avenue at East 24th Street
Cleveland, Ohio 44115

Telephone: (216) 687-2576
FAX: (216) 687-9280

MEMORANDUM

TO: Ms. Kathryn Watkins, Grants Manager, Research Services

FROM: Dr. Kalil Alkasab, Professor, Mechanical Engineering Department

DATE: June 15, 1995

SUBJECT: Summary of Research Accomplished Under Grant No. NCC 3-17

From 1980, I was the director and principal investigator on the cooperative research agreement NCC 3-17 between Cleveland State University (CSU) and NASA Lewis Research Center (NASA-LeRC). Dr. Alden F. Presler served as the NASA Project Leader and Technical Officer. The work at CSU was carried out as graduate program with me as thesis advisor.

The project goal was to develop comprehensive systems models for prototype phosphoric acid electrolyte fuel cell power plants, and to provide computer codes for these models. Detailed models were developed for the major system components, such as the regenerative catalytic fuel processor, and the multi-cell, high temperature electrolyte power section. An efficient optimization scheme was devised for the entire system to enhance trade-off studies of both costs and operational parameters. Because the power density and waste heat dissipation in a multi-cell power section are highly asymmetric, a three dimensional performance model of the fuel cell power section was constructed for analyzing the complex interrelationship geometry, electrochemistry, and heat transfer modes on fuel cell performance and economics.

These basic studies were followed by research on the response of the complex fuel cell system to unsteady state, transient, or catastrophic changes in operating conditions. This had been an unexplored, complicated problem for system design. The transient heat transfer-chemical reaction/interactions in both the hydrocarbon fuel reformer and the fuel cell stack were difficult to analyze and model. The solutions for transient systems operation were the subject of the doctoral thesis of Cheng-Yi Lu, under my direction as thesis advisor.

The program then focused on performing a more detailed experimental and analytical study of cooling plate heat transfer in order to be able to design cell stacks minimizing thermal stress problems. A fuel cell power plant model was constructed with cooling loads. The design and analysis of this system was the subject of the doctoral thesis of Ali Abdul-Aziz, under my direction as thesis advisor.

The experimental rig at CSU has been utilized in a more detailed experimental and analytical study of transient heat transfer in the cooling plate of a fuel-cell stack. This work has been documented in a third doctoral thesis by R. Ridha. In this later study, new instrumentation permitted more detail in the confirmation of analytical prediction.

The project goals have been attained. The excellent and comprehensive computer codes became fully operational in the fuel cell program office at NASA LeRC where they were used in the formulation of technology decisions. The experimental rig provided critically needed engineering data for the fuel cell simulation programs. Equally important was the establishment of a continuing university program for research in fuel cell systems technology analysis.

Specifically, the product, or output, of the CSU/NASA fuel cell project is as follows:

1. Six programs compiled and operational on the NASA LeRC mainframe computer.

2. Four manuals which are documentation for the first four computer programs. These manuals are NASA Contractor Reports (CR)

3. A Ph.D. thesis describing the transient analysis of the fuel cell system.

4. A Ph.D. thesis which mapped the complex steady state heat transfer process within a simulated fuel cell power stack.

5. A Ph.D. thesis which mapped the transient heat transfer process within a simulated fuel cell power stack.

6. Seven papers presented at international symposia on energy. These present results and interpretation of several computer programs.

7. Eleven papers to date published in the archival literature.

The programs and reports are described in more detail in the attachment to this report. The manuals are designated in the attachment by a NASA CR number.

The sustained research, conducted under my direction, has made the CSU/NASA fuel cell systems analysis capability unique in the nation fuel cell program of the Department of Energy. This has been much needed pioneer work, and most useful in one of the most promising of the advanced electrical energy producing technologies. The complex analytical models were treated numerically by finite element programming techniques.

The successful program was honored with a special certificate of recognition to me as the principal investigator, in 1986 by NASA for the "Creative Development of a Technical Innovation". The technical innovation was the composite block of computer programs then in use by the fuel cell project office.

During 1988, some administrative personnel changes took place at CSU which was followed by sudden and unjustified termination, by NASA-Lewis, of the NCC 3-17 Cooperative Agreement. But in spite of the hardship imposed by the loss of the grant financial support, my graduate students and myself continued working on the research project until its completion and documentation of the final results in a doctoral thesis and two publications in 1994. However, because of a communication breakdown with NASA-Lewis, I was not even aware of any need for Agreement "Closeout Procedures" until a few days ago when I was informed about it by the CSU Office of Research Services.

K.A. Alkasab, Ph.D
Professor of Mechanical
Engineering

ATTACHMENT

Reports, papers, and programs prepared under the Cleveland State University (CSU)/NASA Lewis Research Center (NASA LeRC)) cooperative agreement NCC3-17, "Computerized Mathematical Models for Optimum Phosphoric Acid Fuel Cell Systems".

Project Leader: Dr. K. A. Alkasab, CSU
Technical Officer: Dr. A. F. Presler, NASA LeRC

1. Computer programs compiled and operational on the NASA LeRC mainframe computer (1982-1988).

    a. Steady state fuel cell powerplant performance code.
    b. Fuel cell powerplant costing and economics model code.
    c. Fuel cell powerplant cost and performance optimization code.
    d. Three dimensional fuel cell stack steady state performance code.
    e. Fuel cell powerplant network analysis and design code.
    f. Transient fuel cell powerplant system and component performance code.

2. Doctoral thesis, CSU (12/83), "Transient Responses of the Phosphoric Acid Fuel Cell Powerplant System", Cheng-yi Lu.

3. Doctoral thesis, CSU (8/85), "Effects of Cooling Parameters on Heat Transfer and Temperature Distribution in Phosphoric Acid Fuel Cell Stack", Ali Abdul-Aziz.

4. Doctoral thesis, CSU (9/92), "Experimental Determination of the Effects of Transient Operation of Fuel Cell Stack on Heat Transfer and Temperature Distribution in the Electrodes", R. Ridha.

5. NASA Contractor Reports

    CR-174638 (2/84) "Phosphoric Acid Fuel Cell Powerplant Performance Model and Computer Program", K. A. Alkasab and C. Y. Lu.

    CR-174720 (5/84) "Manual for the Phosphoric Acid Fuel Cell Powerplant Cost Model and Computer Program", K. A. Alkasab and C. Y. Lu.

CR-174721 (5/84) "Manual of Phosphoric Acid Fuel Cell Powerplant Optimization Model and Computer Program", K. A. Alkasab and C. Y. Lu.

CR-174722 (5/84) "Manual of the Phosphoric Acid Fuel Cell Powerplant Three Dimensional Model and Computer Program", K. A. Alkasab and C. Y. Lu.

Conference Presentations and Archival Publications:

Alkasab, K. A., Presler, A. F., and Lu, C. Y., "Thermodynamic and Performance Models for the Phosphoric Acid Fuel Cell Systems". Proceedings 6th IASTED International Symposium on Energy '83, San Francisco, May 16-18, 1983.

Alkasab, K. A., Lu, C. Y., and Presler, A. F., "Optimized Cost and Performance Model of Phosphoric Acid Fuel Cell Power Plant". Proceedings 8th IASTED International Symposium on Energy '83, Orlando, November 9-11, 1983.

Alkasab, K. A., Lu, C. Y., "Transient Effects of Changing the Electrical Load on the Performance of Phosphoric Acid Fuel Cell Power Plant". Proceedings 8th IASTED International Symposium on Energy '83, Orlando, November 9-11, 1983.

Alkasab, K. A., Lu, C. Y., "Dynamic Analysis and Simulation of Phosphoric Acid Fuel Cell Power Plant". Proceedings IASTED International Conference on Energy and Environmental Systems '84, Nice, France, June 19, 1984.

Lu, C. Y. and Alkasab, K. A., "Computerized Mathematical Model for Evaluating Transient Responses of Steam-Methane Fuel Processor". Proceedings IASTED International Conference on Energy and Environmental Systems '84, Nice, France, June 9, 1984.

Alkasab, K. A. and Presler, A. F., "Steady State Computerized Model for Phosphoric Acid Fuel Cell Power Plant Performance", Electrochemistry and Electrochemical Engineering Journal, Vol. 1, No. 7, 1983.

Alkasab, K. A., Lu, Cheng-Yi and Presler, A. F., "Optimized Cost and Performance Model of a Phosphoric Acid Fuel Cell Power Plant", International Journal of Energy Systems, Vol 4, No. 3, pp. 88-96, 1984.

Alkasab, K. A., Presler, A. F., and Lu, Cheng-Yi, "Thermodynamic and Performance Model for Phosphoric Acid Fuel Cell System", International Journal of Energy Systems, Volume 5, No. 1, pp. 1-8, 1985.

Alkasab, K. A. and Lu, C. Y., "Transient Effects of Changing the Electrical Load on the Performance of Phosphoric Acid Fuel Cell Power Plant", International Journal of Energy Systems, Volume 5, No. 1, pp. 9-17, 1985.

Alkasab, K. A. and Lu, Cheng-Yi, "Computerized Mathematical Model for Evaluating Transient Responses on Steam-Methane Fuel Processor", International Journal of Energy Systems, Vol. II, No. 2, pp. 96-102, 1991.

Alkasab, K. A., and Lu, C. Y., "Dynamic Analysis and Simulation of Phosphoric Acid Fuel Cell Power Plant, Part I: The Mathematical Model", International Journal of Energy Systems, Vol. II, No. 3, pp. 136-140, 1991.

Alkasab, K. A. and Lu, Cheng-Yi, "Dynamic Analysis and Simulation of Phosphoric Acid Fuel Cell Power Plant, Part II: Computer Modelling and Simulation", International Journal of Energy Systems, Vol II, No. 3, pp. 141-145, 1991.

Alkasab, K. A. and Abdul-Aziz A., "Effects of Coolant Parameters on Steady State Temperature Distribution in Phosphoric Acid Fuel Cell Electrode", Proceedings of the 26th Intersociety Energy Conversion Engineering Conference, Vol. 3, pp. 546-55; August 4-9, 1991, Boston, Massachusetts.

Abdul-Aziz, A. and Alkasab, K. A., "Measurement of the Effects of Thermal Contact Resistance on Steady State Heat Transfer in Phosphoric Acid Fuel Cell Stack", Proceedings of the 26th Intersociety Energy Conversion Engineering Conference, Vol 3, pp. 558-563; August 4-9, 1991, Boston, Massachusetts.

Abdul-Aziz, A. and Alkasab, K.A., "Performance of Serpentine Passages in the Cooling System of a Posphoric Acid Fuel Cell Stack", International Journal of Heat Transfer, Thermodynamics, and Fluid Mechanics. Volume 8, No. 1, January 1994.

Alkasab, K.A. and Ridha, R. "Effects of the Cooling System Parameters and Stack Pressure on PAFC Electrode Transient Heat Transfer and Temperature Distribution", presented at the "First Spacecraft Thermal Control Symposium", Albuquerque, New Mexico, November, 1994.

Alkasab, K.A. and Ridha, R. "Measurement of the Effects of Thermal Contact Resistance on Transient Heat Transfer in Phosphoric-Acid Fuel Cell Stack", presented at the "First Spacecraft Thermal Control Symposium", Albuquerque, New Mexico, November 1994.